

Feeding Responses of Pacific Snappers (genus *Lutjanus*) to the Yellow-bellied Sea Snake (*Pelamis platurus*)

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ABSTRACT—Previous studies indicate that Pacific fishes refuse to attack the yellow-bellied sea snake (*Pelamis platurus*). Visual and non-visual cues are thought to be used to identify this snake. Three species of Pacific snappers – *Lutjanus aratus*, *L. argentiventris*, and *L. guttatus* – were tested for reactions to pieces or extracts of *P. platurus*. Snappers presented with carcass pieces of a variety of stimulus animals regurgitated *P. platurus* more than others; one experiment was inconclusive. Snappers presented in darkness with pieces of stimulus animals attached to clips removed fewer *P. platurus* pieces than those of other species. Pieces of *P. platurus* skin were regurgitated more frequently, and removed from clips less frequently, than were pieces of skinned carcass or control animals. Large pieces (5.0 g) of *P. platurus* were regurgitated and rejected more often than were small pieces (1.3 g). Snappers regurgitated and rejected fish pieces treated with a chloroform: methanol extract of *P. platurus* more than pieces treated with solvent alone. This study indicates that snappers detect chemicals from this snake.

INTRODUCTION

The yellow-bellied sea snake (*Pelamis platurus*) is found from the west coast of Central America to the east coast of Africa [1]. Although predation pressure in tropical Pacific waters is notoriously intense [2], no species has been observed to eat this highly venomous, pelagic serpent. A couple of presumed predators (rather than scavengers) have regurgitated *P. platurus* [3, 4], but stomach content analyses of a variety of predatory fishes – 457 fishes representing 25 species from Panama [1], 186 dolphins (*Stenella* spp.) and 79 tuna (*Thunnus albacores*) from the eastern Pacific [5], approximately 1000 sharks (mostly *Carcharhinus falciformis*) from Baja California to Costa Rica (S. Kato, pers. comm.), and thousands of sharks from around Australia [6, 7] – failed to indicate this snake's remains. Heatwole [6] inspected 19 species of marine snakes in Australian waters for predator-induced injuries and found that *P. platurus* was the only amply represented species that lacked any sign of attacks by fishes. Wounds in *P.*

platurus from the eastern Pacific have been documented, but at least some of these appear to be man-made rather than caused by would-be predators [8].

Observations of the reactions of birds and predatory fishes to *P. platurus* indicate that this snake is avoided. Naive herons and egrets in Panama presented with several eels, a terrestrial snake, and *P. platurus* fled only from the latter [9]. A variety of teleost and elasmobranch fishes refused to attack *P. platurus* or regurgitated pieces of this snake if they were ingested [10].

The cues by which potential predators recognize sea snakes have not been studied systematically, but several authors suggest that the conspicuous yellow (ventral) and black (dorsal) coloration of *P. platurus* acts as an aposematic signal [1, 6, 10, 11]. Rubinoff and Kropach [10] state that other cues also may be involved since snake pieces were rejected by Pacific fishes even after the snakes' color patterns had been modified with marking pens, when snakes were skinned, and when snake pieces were wrapped in squid flesh. Rubinoff and Kropach [10] suggest that fishes identify snakes by chemical cues.

This study examines the feeding reactions of

Pacific snappers (*Lutjanus* spp.) to pieces of *P. platurus* and other animals, and tests the acceptability to the fishes of different sized *P. platurus* pieces and those from different body parts. In addition, the reactions of snappers to chemicals extracted from *P. platurus* are examined.

The *Lutjanus* species used in this study are found primarily on the continental shelf over rocky or sandy substrates [12], where they could encounter sea snakes. Adult *Lutjanus* spp. generally are non-specialized feeders [13, 14]; they therefore were deemed appropriate to test as potential predators of sea snakes. Since some of the snappers tested in this study fed regularly only in darkness (at night), the descriptions and results of diurnal and nocturnal feeding tests are given separately.

DIURNAL TESTS

Reactions to different species

Methods: Six mullet snappers, *Lutjanus aratus* (total lengths = 28–42 cm), were maintained together in an 18.0×6.6 m tank filled one meter deep with recirculating water. The mean water temperature in this and other tanks ranged from 27 to 29°C. These fish had been captive for at least one year, during which they were fed shrimp on an irregular schedule. They were fed shrimp each of two days before testing began.

Pieces of *P. platurus*; two fishes, *Tylosurus fodiator* and *Pomadasys panamensis*; and a squid, *Lolliguncula panamensis*, were presented to the snappers. The snakes used in this and in other experiments ranged from 34 to 62 cm (total lengths). Stimulus animals were sacrificed and kept frozen no more than two days before material from them was used, unless stated otherwise.

The stimulus animals were thawed and pieces, including integument and muscle, were cut from them (1.2–2.3 g). Pieces of squid were taken from the mantle. All pieces were wrapped in aluminum foil, kept frozen, and thawed at least 20 min before being presented to the fish.

Pieces of the stimulus animals were dropped one at a time to the snappers. If a piece was ingested and not regurgitated within one minute, the next

stimulus animal was presented. Observations on fish that regurgitated and reingested a piece were continued for an additional three minutes, beginning the moment the food was reingested. Fish that accepted a piece of stimulus animal after another fish had regurgitated it also were observed for an additional three minutes. Rejection was scored if a piece was ingested, regurgitated, and not consumed by any fish within three minutes of the last regurgitation. A session refers to the period during which the reactions of one or more fish to a piece of stimulus animal were observed.

The snappers were tested until a total of 30 pieces of each stimulus animal were consumed or regurgitated during tests over two consecutive days. Tests were conducted between 13:00 and 16:00 hr.

Results: *P. platurus* pieces were regurgitated 23 times during eight sessions; no other pieces were regurgitated and none were rejected. The Fisher exact-probability test indicates that regurgitations occurred during significantly more sessions with *P. platurus* pieces than with the other species ($P=0.002$).

Methods: Five yellow tail snappers, *L. argenteiventris* (total lengths = 22–38 cm), and four spotted rose snappers, *L. guttatus* (19–36 cm), were maintained in a 4.4×4.0 m tank filled one meter deep with recirculating sea water. These fishes had been captive for 20 days before testing and were fed pieces of squid on each of three days before testing began.

The stimulus animals were *P. platurus*; two fishes, *Oligoplites mundus* and *Tylosurus fodiator*; and an octopus, *Octopus vulgaris*. Pieces of stimulus animals were prepared as described in the previous experiment.

Fishes were tested for four consecutive days between 12:00 and 14:00 hr, with responses to ten pieces of each stimulus animal scored per day.

Results: *P. platurus* pieces were regurgitated four times during three sessions; no other pieces were regurgitated and none were rejected. The Fisher exact-probability test fails to indicate that this trend is significant ($P>0.10$).

Responses to different sized *Pelamis* pieces

Methods: Five *L. argentiventris* tested in the previous experiment were kept together in a 4.4×4.0 m tank. They were fed shrimp each of two days before testing. Small (1.3 g) and large (5.0 g) pieces of *P. platurus* were freshly cut and presented to the snappers. Ten pieces each of small and large snakes were presented to the fish each day for three consecutive days between 10:00 and 11:00 hr. During these tests, fish sometimes approached the snake pieces, touched them with their snout, and moved away without ingesting them.

Results: The small pieces of *P. platurus* were regurgitated during one session; none were rejected. The large pieces were regurgitated or refused after snout contact during ten sessions; five were rejected. The Fisher exact-probability test indicates that large pieces were refused and rejected during significantly more sessions than were small pieces ($P < 0.005$ for both measures).

Acceptability of different *Pelamis* body parts

Methods: Five *L. argentiventris* were presented with pieces of the following parts of *P. platurus*: muscle (1.0–1.5 g), dorsal whole skin, ventral whole skin (0.9–1.6 g), and shed skin (0.7–1.2 g). The snakes from which the muscle and whole skin samples were obtained were decapitated, eviscerated, and their whole skin was cut away from the carcass. The dorsal (black) and ventral (yellow) skin were separated. Shed skins, pooled from several collected off the surface of the snakes' aquarium, were wrapped in aluminum foil and kept frozen. Each piece of shed and whole skin was folded and tied to present a compact morsel to the fish. Pieces of squid mantle (2.5 g) served as controls. A total of 12 pieces of each item was presented to the fish, six in each of two consecutive days. Tests were run between 12:00 and 13:00 hr.

Results: *P. platurus* shed skins were regurgitated 11 times during eight sessions; they were rejected in seven sessions. No other pieces were

regurgitated. The Fisher exact-probability test indicates that shed skins were regurgitated and rejected during significantly more sessions ($P < 0.002$ for both measures).

Methods: Four *L. guttatus*, maintained in a 4.4×4.0 m tank filled 2.2 m, were tested as described above, except that the fish *Vomer declivifrons* was used as the control animal. Six pieces of each item were presented, three in each of two consecutive days.

Results: The total number of sessions during which *P. platurus* dorsal, ventral, and shed skins were regurgitated (and total regurgitations) were 6 (7), 4 (10), and 4 (6), respectively. Rejection of these materials occurred during 6, 4, and 4 sessions respectively. No regurgitation was observed with either fish or *P. platurus* skinned carcasses. The Fisher exact-probability test indicates that, despite the small sample size, snake skins were regurgitated and rejected during more sessions than were pieces of fish or skinned snakes ($P < 0.05$ in all cases).

Responses to *Pelamis* extracts

Methods: Four *L. guttatus* (total lengths = 37–40 cm) were captured and maintained in a 9.0×6.6 m tank for one month before regularly accepting food (pieces of various fishes). They were fed fish three days before testing.

Fifteen snakes (total lengths = 34–36 cm) were cut into 5 cm pieces and placed into one liter of a chloroform:methanol (2:1 v/v) solution. The solution was heated (40°C) for several hours and filtered. The filtrate was placed over a water bath (60°C) on a rotary evaporator for 2 hr, after which an aqueous solution was poured off and saved. The remaining residue was dissolved in 150 ml of chloroform and kept 13 hr in an open glass beaker under ventilation to remove the solvent. A total of 0.31 g of residue remained after the chloroform had evaporated. This residue was redissolved in 25 ml of chloroform.

Strips of the integument and muscle of a fish (*Scomberomorus sierra*) were cut into 4.5 g pieces. The experimental pieces were soaked for 10 hr in

the aqueous snake extract solution and were injected with 0.5 ml of the chloroform-soluble carcass extract (some of which flowed out on to the surface). The control pieces were soaked in a distilled water:methanol solution (1:1 v/v) for 10 hr and injected with 0.5 ml of chloroform. Both experimental and control fish pieces were wrapped in aluminum foil and allowed to air-dry for 4 hr. They were kept refrigerated (4°C) for several days during tests.

Fish were presented with 5–7 items a day between 09:00 and 13:00 hr and were observed for one minute. If regurgitation and reingestion occurred, the session was extended for three minutes. A total of 17 pieces each of control and *Pelamis*-treated pieces were presented.

Results: The control pieces were regurgitated twice during one session; none were rejected. The *Pelamis*-treated pieces were regurgitated a total of 31 times during eight sessions and rejected in six sessions. The Fisher exact-probability test detects significantly higher rates of regurgitation ($P < 0.01$) and rejection ($P < 0.001$) with *Pelamis*-treated pieces.

NOCTURNAL TESTS

Reactions to different species

Methods: Seven *L. guttatus* (total lengths = 23–28 cm) were captured and maintained for one month in a 9.0×6.6 m tank filled to 1.1 m deep. These fish refused to eat pieces of fish offered to them during the day, but at night they accepted food attached to wooden clips suspended from a string immersed into their tank. The string (11 m) was tied at opposite ends along one side of the tank. A metal weight was attached to each of nine wooden clips, placed 60 cm apart on the string. The food items attached to the clips were situated from 20 to 100 cm from the floor of the tank during the test.

Pieces from three stimulus species were presented: *P. platurus*, *Octopus vulgaris*, and the fish, *Scomberomorus sierra*. Each piece (3.5 g) included the integument and underlying muscle tissue. Three pieces of each stimulus animal were

presented during each one hour session. The pieces were attached in a random order on the clips, the lights were extinguished, and the string was lowered into the water; fish, therefore, were not permitted visual access to the items.

After one hour, the string was raised out of the water, the lights were turned on, and the pieces remaining on the string were noted. Four consecutive sessions were run each of two nights, giving 24 presentations of each stimulus animal. All nocturnal tests were conducted between 20:00 and 02:00 hr.

Results: A total of 20, 6, and 1 pieces of *P. platurus*, octopus, and fish, respectively, remained attached to the clips. The χ^2 test indicates that significantly more snake pieces were left attached than were the other items ($P < 0.001$).

Reactions to marine and terrestrial snakes

The same fish, facilities, and protocol described in the previous test were used. Fish were presented with pieces (3.5 g) of *P. platurus*, western diamondback rattlesnakes (*Crotalus atrox*), and the fish, *Scomberomorus sierra*. The rattlesnakes were obtained in Nolan County, Texas. The carcasses of both *Pelamis* and *Crotalus* had been kept frozen (–70°C) for 5 months and shipped on dry ice. A total of 36 of each item was presented to snappers over three nights.

Results: A total of 31, 9, and 0 pieces of *P. platurus*, rattlesnake, and fish, respectively, remained attached to the clips. The χ^2 test indicates that significantly more *P. platurus* pieces were left attached than were the other items ($P < 0.001$).

Acceptability of different *Pelamis* body parts

The same fish, facilities, and protocol described in the previous two tests were used in this experiment. Fish were presented with pieces of *P. platurus* whole skin (1.4 g), skinned carcass (3.2 g), and a fish (*Epinephalus* sp.) (3.5 g). A total of 36 of each item was presented to snappers over three nights.

Results: A total of 24, 15, and 0 pieces of *Pelamis* skin, *Pelamis* carcass, and fish, respective-

ly, remained attached to the clips. The χ^2 test indicates significantly more pieces of skin were left attached than were pieces of snake carcass or fish ($P < 0.05$).

DISCUSSION

The reactions of *Lutjanus* spp. to the stimulus animals presented in this study indicate that *P. platurus* is least acceptable as food. Bullseye puffers (*Sphoeroides annulatus*) also rejected *P. platurus* more frequently than pieces of fishes or squid [8], as did spotted cabrillas (*Epinephelus analogus*) (Weldon, preliminary observation). These results agree with initial observations by Rubinoff and Kropach [10] on the rejection of this snake by numerous Pacific fishes.

Kropach [11] suggested that *Lutjanus* spp. attend to visual cues in avoiding *P. platurus*, *L. aratus* and *L. argentiventris* immediately and rapidly swim away from *P. platurus* introduced into their tanks, even when dead snakes coated with varnish were used (Weldon, preliminary observation). It seems likely that visual stimuli do elicit avoidance by snappers, but other cues may also be involved.

The reactions of fishes during the diurnal tests were scored if the items presented were contacted by the snout or taken into the oral cavity. Visual cues may have been discerned, but the decision to swallow or regurgitate these materials likely was based upon post-ingestive information of a chemical or mechanical nature. The results of the nocturnal experiments indicate that snappers discriminated between pieces of *P. platurus* and other animals under conditions where no visual information was available. The increased frequencies with which larger *P. platurus* pieces were regurgitated and rejected in tests with different sized pieces probably were due to mechanical difficulties encountered in swallowing.

MacLeish [15] describes an "underwater taste test" where Australian fishes regurgitated the carcass of a sea snake (not *P. platurus*). It has been unclear, however, whether the refusal of snakes by fishes is elicited by chemicals. The greater frequencies of regurgitation and rejection of fish pieces treated with *P. platurus* extract,

compared to those observed with solvent-treated controls, support the hypothesis that fish attend to chemicals to avoid ingesting this snake. The solubility of these substances suggests that they are lipoidal.

The results of the nocturnal test comparing fishes' reactions to *P. platurus* and the rattlesnake, *Crotalus atrox*, suggest that snappers discriminate between these species on the basis of non-visual cues. Tests of the reactions of fishes to extracts of various snakes are needed. While *P. platurus* appears to be relatively predator-free, other marine snakes occasionally are eaten by sharks [7, 16]. Whether snakes differ in palatability is unknown.

Pacific fishes, including *Lutjanus* spp., have been observed to reject *P. platurus* carcasses bereft of skin [1, 10]. No pieces of skinned *P. platurus* were regurgitated by the snappers in the diurnal tests here. *L. guttatus* rejected ventral, dorsal, and shed skins of *P. platurus*, and *L. argentiventris* rejected pieces of shed skin, which probably were recognized as inedible. The results of the nocturnal test with *L. guttatus* also indicate that whole snake skin is less acceptable than the skinless snake carcass. It is unclear whether the decision to regurgitate or eat different parts of *P. platurus* is based upon chemical or mechanical cues since the materials used differ in texture and consistency. Tests of fishes' reactions to extracts from different body parts are needed to determine whether unpalatable chemicals are localized in the body of *P. platurus*.

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